Industrial machining of Douglas Fir with various tools and materials

Proceedings of The 15th International Wood Machining Seminar

I-W-M-S-15

July 30 - August 1, 2001
Los Angeles, California, USA

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Wood Machining Institute
Berkeley, California
www.woodmachining.com

Published by
Wood Machining Institute
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Berkeley, CA 94701-0476, USA
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CHAPTER 7: MONITORING AND PROCESS CONTROL 509

Industrial Machining of Douglas Fir with Various Tools and Materials

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Abstract

Tests of industrial machining process were performed on Douglas fir from European plantations by the means of various tools and materials. Spindle shaping process was performed by using carbide tipped moulding tools providing very good quality surfaces. PCD moulding tool was responsible of fuzzy grain. European Douglas-fir do not asks for different milling setting compared to other softwood used in Europe (spruces, firs, pines).

Introduction

At present, the Douglas fir is becoming an increasingly important timber resource in Europe. In fact, growing quantities of timber coming from artificial European plantations are available.

The fast grown European timber presents large annual rings. Within the ring the late-wood density is high (0.9÷1) while the early-wood density is very low (0.3). This huge difference affects the quality of the surfaces due to machining process (e.g. planing and spindle shaping machining) and therefore the quality of final products is not satisfactory. In fact, the usual process conditions such as feeding speed, rake angles of the tools, cutting materials, etc. are not completely suitable for machining this type of timber. Nevertheless, the surface quality of the European resources may be improved through a suitable machining process. The goals of this work is to improve the process parameters in order to achieve an acceptable surface quality, by using tools made with different materials such as carbide, diamond and coated tools.

1 The surface quality

The quality of the timber surface resulting from a machining process can be evaluated through a binary judgement like "accepted / rejected". This method, even though effective, allows few statistical data processes. Nevertheless, the human synthesis is able to summarise effectively the influence of different properties such as texture, colour, brightness, roughness, thickness regularity and many others. Some procedures have been proposed to improve the effectiveness of the visual and tactile methods.

It should be noted that "surface quality" is a property which depends upon various factors. It changes according to the wood species, to the final use, to the epoch, and to other variable parameters. The machining tests are standardised by ASTM D-1666-87 [1]. The procedures presented in this standard cover such common operations as planing, shaping, turning, boring, mortising and sanding. It includes practical methods for qualitatively evaluating and interpreting the results, through a grading method describing the quality of surfaces.

A similar method for evaluating the planing process was conceived by Petrocchi [2] and proposed in a previous work by our team [3]. It is based on the ASTM standard with some improvements and adaptations.

2 Material and method

2.1 Tools and processes

Each test specimen was carefully visually examined for process defects after each run. The tests were carried out in an industrial joinery by using different processes, tool geometry, tool materials, and feeding velocities as follows:

1. planing process with planing machine (characteristics: (i) r.p.m. 6500; (ii) feeding speed 10 and 15 m/min.) provided with carbide tipped knives on a special helicoidal cutterhead, as in Figure 1;
2. spindle shaping process with shaping machine (characteristics: (i) r.p.m. 6500; (ii) feeding speed 10 m/min.) provided with carbide tipped moulding tools;
3. spindle shaping process with shaping machine (characteristics: (i) r.p.m. 6500; (ii) feeding speed 10 m/min.) provided with Polycrystalline Diamond (PCD) moulding tools.

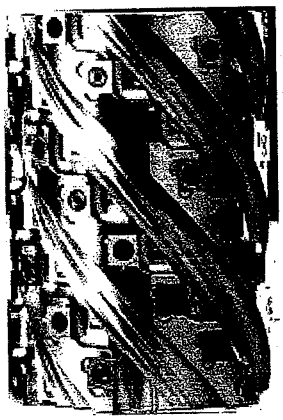

Figure 1. Carbide tipped knives on the special helicoical cutterhead.

2.2 The machining quality

The machining quality was graded by visual examination on the basis of five groups as follows:

Grade 1, excellent;
Grade 2, good;
Grade 3, fair;
Grade 4, poor;
Grade 5, very poor.

The Grades 1 and 2 provide fully acceptable quality. By contrast from Grade 3 up to 5 the machined timber could be rejected, according to final uses. The machining defects are described by the standard according to various defect types, as follows:

- the raised grain is a roughened condition of the surface of timber in which the hard late-wood is raised above the soft early-wood but is not turned loose of it;
- the fuzzy grain is due to small particles or groups of fibres which did not sever clearly in machining but which stand up above the general level of the surface;
- the torn grain is the part of the wood turning out in dressing;
- the chip marks are the shallow dents in the surface caused by chips that have clung to the knives instead of passing off in the exhaust as intended.

The procedures adopted are completely described in section 11 of ASTM D-1666-87; in this standard are also published reference photos describing the different defects and the grades. Some adaptations according to Petrocchi were adopted (different MC, different cutting depth, more data collected). The Sample Data Sheet used is the same as in [3].

Due to the peculiar properties of European Douglas fir Negri and Goli [4] proposed by a different defect, as follows:

- the pressed grain is due to fibres or groups of fibres partially cut by the tool and pressed onto the wood surface (as it is shown in Figure 2).

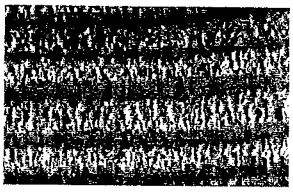

Figure 2. Pressed grain grade 4 (softwood)

2.3 Types of wood surfaces observed

For planing process with helicoidal cutterhead, the timber surfaces were graded into three groups according to the occurrence of timber defects able to induce machining defects, as follows:

- the Defect-Free Timber (DFT) was the area of the board without timber defects such as knots and grain deviations. It described the machining defects due to the basic properties of the species without the influence of the timber defects;
- the Timber with Defect (TwD) was the wood on which the machining defects were related to the timber defects occurrence. We took into account only the timber defects able to induce machining defects, such as knots and grain deviation. This allowed us to relate the machining defects to the timber defects;
- the Whole Board Grading (WBG = Defect Free Timber + Timber with Defect), was the group describing the whole board. The grade was carried out from the DFT and TwD groups by choosing the worst defect found. This allowed us to obtain a global description of the board.

Moreover, in planing process with helicoidal cutterhead two feeding velocities, respectively 10 and 15 m/min, were tested. For the Chip Marks no differences due to the timber defects were envisaged, so the grading was performed directly according to the Whole Board Grading. The other machining defects (Raised Grain, Fuzzy Grain and Torn Grain) will be shown in the paragraph Results both according to the DFT/TwD groups and according to the WDG group.

By contrast, for spindle shaping processes, only the timber without wood defects was observed so that the results are expressed only in the Defect Free Timber group. Moreover, only one feeding velocity was tested. The total sample was of about 312 surfaces observed on 78 pieces of Douglas fir grew in France (*Pseudotsuga menziesii Franco, var. Menziesii*) 50 cm length, 50 mm wide, 50 mm thick.

3 Results

The tests of planing process through carbide tipped knives on a helicoidal cutter head are in Table 1. The results are divided according the different type of timber surfaces observed (such as Defect-Free Timber, Timber with Defects and Whole Board Grading), and the two feeding velocities tested, respectively 10 and 15 m/min. In order to point out the machining conditions providing a low quality of machined surface, for each machining defect the worst qualities (grades from 3 to 5 corresponding to fair, poor and very poor quality) are provided in the rows marked "Σ 3, 4, 5".

Table 1. Percentage of faces affected by processing defects, divided according to the groups of defects mentioned above, which occurred during the planing process performed through carbide tipped knives on a helicoidal cutter head.

Planing process with carbide tipped knives on helicoidal cutter head		10 m/min feeding velocity				15 m/min feeding velocity			
	GRADE	Raised Grain %	Fuzzy Grain %	Torn Grain %	Pressed Grain %	Raised Grain %	Fuzzy Grain %	Torn Grain %	Pressed Grain %
Defect Free Timber	1	90	33	92	93	98,3	38,3	85	90
	2	10	16	3	7	1,7	36,7	5	8,3
	3	0	31	1	0	0	23,3	5	1,7
	4	0	20	2	0	0	1,7	5	0
	5	0	0	2	0	0	0	0	0
	Σ 1, 2	100	49	95	100	100	75	90	98,3
	Σ 3, 4, 5	0	51	5	0	0	25	10	1,7
Timber with Defects	1	100	100	29,4	23,5	100	100	25	30,5
	2	0	0	20,6	61,8	0	0	13,9	50
	3	0	0	20,6	11,8	0	0	16,7	16,7
	4	0	0	14,7	2,9	0	0	27,7	2,8
	5	0	0	14,7	0	0	0	16,7	0
	Σ 1, 2	100	100	50	85,3	100	100	38,9	80.5
	Σ 3, 4, 5	0	0	50	14,7	0	0	61,1	19,5
Whole Board Grading	1	91,6	33,7	67,4	65,3	96,9	45,8	61,5	64,6
	2	8,4	24,2	8,4	28,4	2,1	35,5	8,3	26
	3	0	29,5	9,4	5,3	0	17,7	10,4	8,3
	4	0	12,6	7,4	1	1	1	13,5	1,1
	5	0	0	7,4	0	0	0	6,3	0
	Σ 1, 2	100	57,9	75,8	93,7	99	81,3	69,8	80,6
	Σ 3, 4, 5	0	42,1	24,2	6,3	1	18,7	30,2	9,4

The results are divided according grading performed on the different type of timber surface, such as Defect-Free Timber, Timber with Defects and Whole Board Grading.

In Figure 3 the planing process performed through carbide tipped knives on a helicoidal cutter head are reported at different feeding velocities on Defect-Free Timber. In Figure 4 the same process was checked on Timber with Defects. For both charts on the Y axis the incidence (%) of the various defects from fair to very poor quality (grade from 3 to 5) is reported. The tests of spindle shaping process were performed by using both carbide tipped and Polycrystalline Diamond moulding tools and the grading process was carried out on surfaces without wood defects (Defect-Free Timber) in order to point out the properties of Douglas fir timber towards these machining processes.

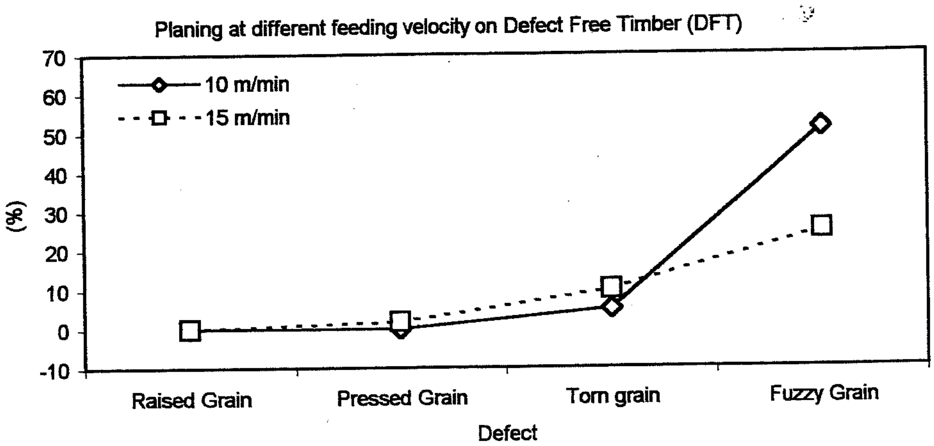

Figure 3. Planing process performed by using carbide tipped knives on a helicoidal cutter head at different feeding velocities on Defect-Free Timber. On Y axis the incidence (%) of the various defects from fair to very poor quality (grade from 3 to 5) is reported

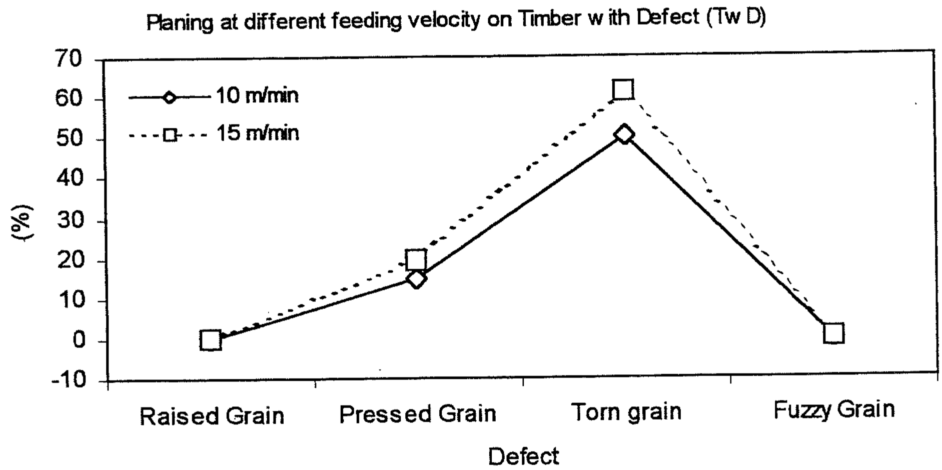

Figure 4. Planing process performed by carbide tipped knives on a helicoidal cutterhead at different feeding velocities on Timber with Defects. On the Y axis the incidence (%) of the various defects from fair to very poor quality (grade from 3 to 5) is reported

The results are reported respectively in Tables 2 and 3, providing the percentage of faces affected by processing defects, divided according to the groups of defect, which occurred during the spindle shaping process.

Table 2. Percentage of faces affected by processing defects, divided according to the groups of defect above mentioned, which occurred during the spindle shaping process performed through carbide tipped moulding tool

Shaping process with carbide tipped moulding tool					
	GRADE	Raised Grain %	Fuzzy Grain %	Torn Grain %	Pressed Grain %
Defect-Free Timber	1	100	75,4	78,7	96,7
	2	0	21,3	8,2	3,3
	3	0	3,3	4,9	0
	4	0	0	4,9	0
	5	0	0	3,3	0
	Σ 1, 2	100	96,7	86,9	100
	Σ 3, 4, 5	0	3,3	13,1	0

Table 3. Percentage of faces affected by processing defects, divided according to the groups of defect above mentioned, which occurred during the spindle shaping process performed through Polycrystalline Diamond moulding tool

Shaping process with Poly-Cristalline Diamond (PCD) moulding tool					
	GRADE	Raised Grain %	Fuzzy Grain %	Torn Grain %	Pressed Grain %
Defect-Free Timber	1	100	21,7	88,3	96,6
	2	0	30	11,7	1,7
	3	0	30	0	1,7
	4	0	18,3	0	0
	5	0	0	0	0
	Σ 1, 2	100	51,7	100	98,3
	Σ 3, 4, 5	0	48,3	0	1,7

In Table 4 both planing and shaping processes are shown towards the occurrence of faces with any defect due to the machining process and the occurrence of faces providing machining defects. In Figure 5 planing and shaping processes performed respectively with carbide tipped knives on a helicoidal cutter head and with moulding tools (both carbide tipped and PCD) at the same feeding velocity were observed on Defect-Free Timber.

Table 4. Planing (carbide tipped knives) and shaping (carbide tipped and PCD moulding tools) processes are shown toward the occurrence of both the faces with any defect due to machining process and the faces providing machining defects

		Faces without	Faces with	Faces without	Faces with
		machining defects			
Feeding velocity		10 m/min		15 m/min	
		%	%	%	%
Planing process with carbide tipped knives on helicoidal cutter head	Defect Free Timber	20	80	28,3	71,7
	Timber with Defects	0	100	8,3	91,7
	Whole Board Grading	12,6	87,4	20,8	79,2
Shaping process with carbide tipped moulding tool	Defect Free Timber	37,7	62,3		
Shaping process with Polycrystalline Diamond (PCD) moulding tool	Defect Free Timber	10	90		

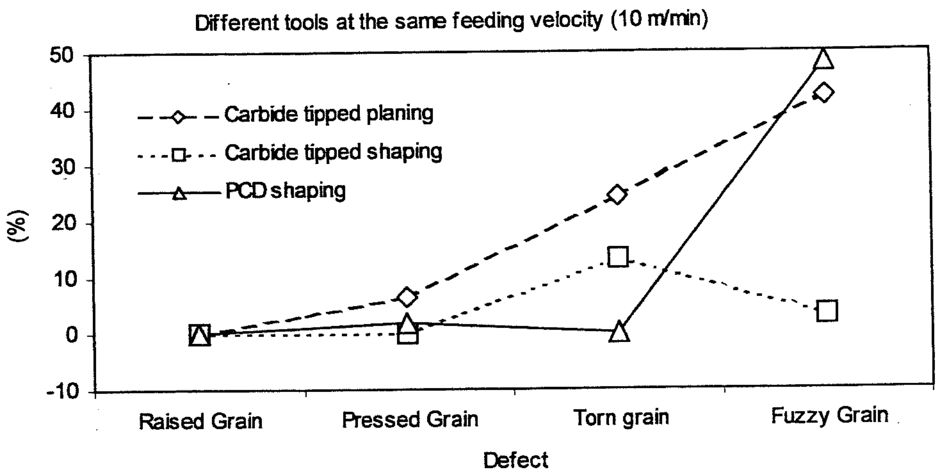

Figure 5. Planing and shaping processes performed respectively with carbide tipped knives on a helicoidal cutterhead and with moulding tools (both carbide tipped and PCD) at the same feeding velocity on Defect-Free Timber. On the Y axis the incidence (%) of the various defects from fair to very poor quality (grade from 3 to 5) is reported

4 Discussion

4.1 Planing process by carbide tipped knives on helicoidal cutter head

The main machining defect provided on timber without wood defects (DFT, Defect Free Timber) is the fuzzy grain for both feeding velocities (10 m/min and 15 m/min), being respectively 51 and 25 % of specimens graded in the worst classes (from grade 3 to 5), as shown in Table1. In the same table the results of machining defects on timber providing wood defects (TwD, Timber with Defects) show that the main defect is torn grain for both feeding velocities, respectively for 50 and 61, 1 % of specimens. By grading the boards considering the machining defects both on free defect timber and on the zones with timber defects (WBG, Whole Board Grading) the relevant defect changes according to the feeding velocity, as follows:

- with 10 m/min the main defect was the fuzzy grain, affecting 42,1 % of specimens, and the second relevant defect was the torn grain, affecting 24,2 % of specimens;

- with 15 m/min the main defect was the torn grain, as it affected 30,2 % of specimens, and the second relevant defect was the fuzzy grain, affecting 18,7 % of specimens.

As shown in Figure 3, a different feeding velocity on Defect-Free Timber provided similar behaviour: no significant incidence for raised, pressed and torn grain; fuzzy grain appears at 15 m/min and its occurrence increases at 10 m/min feeding velocity.

In Figure 4 the machining defects are observed in relationship to the timber defect (Twd, Timber with Defect): in this case fuzzy grain does not appear at all, such as the raised grain. The main relevant defect is the torn grain, followed by the pressed grain. No relevant difference in behaviour at the two feeding velocities were recorded.

4.2 Spindle shaping process by carbide tipped and PCD moulding tools

In Table 2 the percentage of faces affected by processing defects is reported, divided according to the groups of defects already mentioned, and which occurred during the spindle shaping process performed through carbide tipped moulding tool on Defect Free Timber. The sum of defects in the worst classes indicates that the main defect was the torn grain, affecting 13,1 % of specimens. By using a Polycrystalline Diamond moulding tool on Defect Free Timber, the most relevant defect was the fuzzy grain, since it affected 48,3% of specimens, as shown in Table 3.

4.3 Planing and spindle shaping process

The comparison between the planing process and the spindle shaping process at given conditions (any kind of machining defect, machining defect graded in the worst classes from 3 to 5, observations on Defect Free Timber, 10 m/min feeding velocity) as reported in Table 4, showed that:

- 80 % of faces of the specimens presented one or more types of machining defect due to the planing process with carbide tipped knives;
- 62,3 % of faces of the specimens presented one or more types of machining defect due to spindle shaping with carbide tipped moulding tool;
- 90 % of faces of the specimens presented one or more types of machining defect due to the planing process with Polycrystalline Diamond (PCD) moulding tool.

Figure 5 points out the main defects of each type of process/tool combination, at the same given conditions mentioned above:

- raised and pressed grains were never relevant;
- torn grain was relevant by machining with carbide tipped tools both by planing and spindle shaping;
- fuzzy grain heavily affected both specimens planed by carbide tipped tools and specimens spindle shaped by PCD tools.

Some of the phenomena, such as the trend of occurrence fuzzy grain both when decreasing the feed speed (with carbide tipped tools) and when using PCD tools, are not fully explained at this stage of the studies.

5 Conclusions

The Douglas fir presented some defects due to the machining process. The main machining defects were the fuzzy and torn grain on both the specimens with timber defects and defect-free specimens. The chip marks affected the surface quality so badly that this voice is not even reported in the Tables. But we have to keep in mind that it could become a real problem if the vacuum device on the tool machine is not high-performance: then the chips could easily punch the low-density early wood. Even after machining, these low-density areas are still very exposed to punching risks. The raised grain was never a relevant defect, such as the pressed grain.

Previous tests carried out on an ordinary planing machine showed that machining Douglas fir was not always satisfactory [3].

In this study we demonstrate that planing by using suitable tools, such as carbide tipped knives set on helicoidal cutting head, with suitable machining conditions (15 m/min feeding velocity) provided good quality on approx. 70% of specimens (see in Table 1, Whole Board Grading).

The spindle shaping process performed by using carbide tipped moulding tools provided very good quality surfaces (see Table 2) while the PCD moulding tool was responsible for the occurrence of fuzzy grain in half of the specimens machined, as shown in Table 3.

To sum up, European Douglas-fir seems not really asking for very different milling setting compared to the more conventional softwood used in Europe (spruces, firs, pines). A recent comparative study of the surface quality of fir and Douglas-fir after conventional milling tests [5] has showed very closed results for the two species.

Acknowledgements to Menuiseries Pelerin, Chaumont France

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